Chapter 1

Introduction

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Stormwater has traditionally been considered a nuisance, requiring rapid and complete drainage from areas of habitation. Unfortunately, this approach has caused severe alterations in the hydrological cycle in urban areas with attendant, mostly negative, changes in receiving water conditions and uses. This historical "water as a common enemy" approach has radically affected the way urban dwellers relate to water. For example, most residents are not willing to accept standing water near their homes for significant periods of time after rain has stopped.

However, a new, innovative approach to stormwater management is beginning to appear. There are many examples where engineers, planners, landscape architects and others have successfully integrated water into the urban landscape. In many cases, water has been used as a focal point in revitalizing downtown areas. Similarly, many arid areas are looking at stormwater as a potentially valuable resource, with stormwater being used for on-site beneficial uses, instead of being quickly discharged as a waste.

New actual and potential innovative approaches to stormwater management are described in this report. Overviews of individual chapters are presented below.

Chapter 2: Principles of Integrated Urban Water Management

The purpose of this chapter is to review the literature on innovative urban developments, in general, evaluate principles of sustainability, and present the urban stormwater management problem within this broader context. The focus of this report is new urban developments and these developments are at the neighborhood scale. Control methods include source controls at the individual parcel level.

Trends in urbanization during the 20th century are described including the impact of the automobile and subdivision regulations. Urban sprawl has often been the result of such changes. Possible emerging land use forms are described that might be more sustainable than present systems. Issues are presented to help decide whether smaller or larger scale infrastructure systems are preferable. Finally, the sources of runoff in urban areas are described along with a description of their relative importance.

Chapter 3: Sustainable Urban Water Management

Water supply, wastewater, and stormwater systems are explored in this chapter, first individually and then in an integrative manner. Key areas of potential integration of these three functions are reuse of wastewater and stormwater to reduce the required net import of water for water supply. The literature review summarizes previous and on-

going work nationally and internationally to develop more sustainable urban water management systems. A systems view of urban water management was first advocated in the late 1960's. This approach is summarized. Principles for sustainable urban water infrastructure systems are presented.

Urban water budgets provide a way to evaluate the relative importance of the various components of the urban water system. The results of a recently completed national residential water use study are described along with the results of several water budget studies from Europe and Australia. Then, monthly water budgets for Denver, CO and New York City, NY are presented. Lastly, some alternative future urban water scenarios are described ranging from the status quo to aggressive water conservation and reuse programs.

Chapter 4: Source Characterization

The sources of the stormwater pollutants and flows that are likely to be preventing beneficial uses must be recognized and quantified before an effective stormwater management strategy can be implemented. This chapter gives an overview of the obvious stormwater pollutant sources in urban areas, especially natural sources (soils, atmospheric dustfall, and rain) and the washoff of contaminated dirt from pavements (the most popular location for source control efforts). Included in Chapter 4 are summaries of actual sheetflow runoff quality obtained during rains from numerous source areas (roofs, landscaped areas, parking and storage areas, driveways, sidewalks, and streets) for commercial, industrial, and residential land use areas. The chapter concludes describing a study that investigated toxic heavy metal and organic pollutant sources. Information and ideas presented in this chapter can be used to identify significant sources of problem pollutants and understand how stormwater can be better controlled at critical source areas and/or at a downstream outfall.

Chapter 5: Receiving Water and Other Impacts

A critical element to be investigated as part of a stormwater management program is an understanding of the local receiving water problems. This chapter reviews many types of problems that have been identified and documented during studies throughout the country. The list of potential problems is diverse and long, although relatively few may be relevant for any given geographic area. Some of the most common types of receiving water problems that have been investigated relate to aquatic life uses. Numerous studies have compared aquatic life (usually fish and benthic macroinvertebrates) in urban streams with reference streams. Most of the investigations examined toxic pollutant causes of the noted aquatic organism differences, but recent investigations focused more on habitat issues caused by stormwater discharges (e.g., contaminated and fine-grained sediments, unstable streambeds, variable and high flows, and destruction of refuge areas).

Human health issues associated with stormwater discharges are also reviewed. Potential groundwater impacts caused by inadvertent and by designed subsurface disposal of stormwater are also examined. Chapter 5 includes emerging tools that

many States are using to measure receiving water problems, especially bioassessment procedures that integrate numerous relatively inexpensive field measurement components.

Chapter 6: Collection Systems
Stormwater and other wastewater collection systems are a critical link in the urban water cycle, especially under wet-weather conditions. In the context of pollution control, these systems transport sanitary wastewater, stormwater, industrial wastewater, non-point source pollution, inflow, and infiltration. Understanding the problems associated with modern sewer collection systems is enhanced by reviewing the history of collection systems in the U.S. Problems associated with present day collection systems are described including the challenge of infiltration and inflow. The emerging issue of sanitary sewer overflows is discussed. The importance of understanding the nature of sewer solids is described with emphasis on the role of solids in determining sewer design criteria. Innovative sewer design and monitoring systems are discussed.

Chapter 7: Assessment of Stormwater Best Management Practice Technology
The use of stormwater controls to manage the quality and quantity of urban runoff has become widespread in the U.S. and in many other countries. As a group they have been labeled best management practices, or BMPs. Structural BMPs are designed to function without human intervention at the time wet weather flow is occurring, that is, they are expected to function unattended during a storm and to provide passive treatment. Nonstructural BMPs, as a group, are a set of practices and institutional arrangements, both with the intent of instituting good housekeeping measures that reduce or prevent pollutant deposition on the urban landscape.

Much is known about the technology behind these practices, much is still emerging and much remains yet to be learned. Many of these controls are used without full understanding of their limitations and their effectiveness under field conditions. Uncertainties in the state of practice associated with structural BMP selection, design, construction and use are further complicated by the stochastic nature of stormwater runoff and its variability with location and climate. Examination of precipitation records throughout the U.S. reveals that the majority of individual storms are relatively small, often producing less precipitation and runoff than used in the design of traditional storm drainage networks. Chapter 7 describes a number of structural and non-structural BMPs with emphasis on their effectiveness in removing pollutants and in mitigating flow rates. BMP effectiveness in addressing some of the impacts of urban runoff on receiving water systems is also discussed.

Chapter 8: Stormwater Storage-Treatment-Reuse Systems
The overall effectiveness of a variety of stormwater BMP's is evaluated in the previous chapter. Two other aspects of control of stormwater: high-rate treatment and the potential effectiveness of using stormwater for supplemental irrigation, are described in Chapter 8. Presented is a review of ways to evaluate the tradeoff between storage and treatment of wet-weather flows. Then the potential for high-rate operation of

wastewater treatment plants during wet-weather periods is discussed. Stormwater reuse offers the possibility of significantly reducing water demand for irrigation and toilet flushing. The approximate size of on-site storage needed and how it varies with location is presented. A monthly water budget is used as part of this to estimate storage needs.

Chapter 9: Urban Stormwater and Watershed Management: A Case Study
Interest in watershed management has waxed and waned over the past century. During the 1980's, primary reliance was placed on a command and control approach for addressing water resources problems including stormwater. A strong move back to the watershed management approach began a few years ago. Watershed analysis and planning methodologies are reviewed.

A detailed case study of Boulder Creek Watershed (BCW) and Boulder, CO is presented. (This case study emphasizes the analysis aspect of urban stormwater and watershed management. Appendix A in this report is a case study that emphasizes the planning aspect of urban stormwater and watershed management). With the beginning of mining in 1858, the water and land associated with various forms of development had a significant impact on BCW. The watershed has been drastically altered by activities such as mining, urbanization, agriculture and hydropower development. BCW suffered serious early stormwater pollution from the original mining activities.

Thus, nonpoint pollution is an old problem in BCW. The watershed has also been adapted to provide water supply, flood control, recreation, and instream flow needs. The adaptations are both structural and nonstructural. Structural interventions include construction of reservoirs, canals, pipelines, pump stations, hydropower generation, water and wastewater collection and treatment systems, flood control levees, instream and wetland restoration, and imports and exports of water. Nonstructural interventions include flood warning systems, floodplain management, water rights enforcement, water conservation programs, and education about watershed protection.

The end result of all of these interventions is a complex watershed system that has been adapted to serve the needs of society as well as the natural system. This level of development and adaptation is typical of watersheds in the U.S. and other developed areas. Thus a watershed should be dealt with as a system in contrast with isolating system components and ignoring the system’s complexity. While the focus of this report is urban stormwater quality management, these other considerations should also be borne in mind.

Chapter 10: Cost Analysis and Financing of Urban Water Infrastructure
This chapter summarizes water, wastewater, and stormwater infrastructure costs for cities in the U.S. While the main theme of this report is stormwater, some of the innovative ideas proposed would reuse stormwater for reducing water supply demands (e.g., for irrigation water). The effect of dwelling unit density on the demand for water infrastructure is presented. Previous efforts to find the optimum scale of urban water

systems are described. Summary cost functions for a variety of water resources facilities are presented.

Stable funding is an essential ingredient in developing and maintaining viable urban water organizations, whether they are stormwater utilities, watershed organizations, or other organizational forms. Integrated management offers the promise of improved economic efficiency and other benefits by combining multiple purposes and stakeholders. However, the benefits from integrated management exacerbate problems of financing these more complex organizations because ways must be found to assess each stakeholder's "fair share" of the cost of this operation. An overview of utility financing in the water, wastewater, and stormwater areas is presented.

Chapter 11: Institutional Arrangements

Stormwater Management Institutions of the 21st century face many challenges. Federal stormwater permitting requirements will affect most cities. Funding and staffing are likely to remain tight, even though stormwater regulations and requirements continue to expand. Stormwater management will be only one of a long list of issues that must be addressed by local governments. Given the time and budget constraints that staff will face, local governments will have to decide where stormwater management lies relative to other priorities. This is no easy task, given that the benefits of stormwater management can be elusive to quantify.

New stormwater management facilities must be financed and constructed. The public must be better educated on the significance of stormwater issues and stakeholders should be increasingly involved in urban water management. Research must lead to new technologies for treating and retaining stormwater runoff. Institutions will need to issue guidance on complicated and often controversial issues such as riparian corridor preservation, impervious area limitations, conservation easements, innovative zoning techniques and other subjects. Given these challenging tasks, Chapter 11 briefly characterizes the existing models of stormwater management institutions, identifies five essential characteristics of future stormwater management institutions, and describes specific technical and administrative issues that these stormwater management institutions must address.

Further, existing stormwater regulations are transitioning from the promulgation and implementation stages to the enforcement stage, where local governments may face legal challenges, particularly as a result of land use restrictions. Coordination among local, state, federal and private entities is and will continue to be a challenge. Stormwater management institutions have to address both water quality and quantity issues. In some cases, this will require retrofitting existing stormwater quantity structures to address stormwater quality issues and to improve their drainage and flood control function.

A planning case study to illustrate innovative stormwater management in new development is presented in **Appendix**. It is a condensed version of the Southeast

Annexation Area Lake Hart Basin Master Stormwater Management Plan (LHMSMP), City of Orlando, Orange County, FL. The general goals of the LHMSMP are the development of an integrated stormwater, wetland, and open space management system that would balance preservation of natural systems with land development. The general goals are to be accomplished by meeting the following three key objectives in a cost-effective manner: flood control, pollution control, and ecosystem management (which includes wetlands protection, aquifer recharge, and water conservation).